Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Integrated Scheduling Algorithm for Personalized Disease Management Applications

X. Yuan, Member, IEEE, and M. Moges

Abstract— The rapid escalation of American health care costs compels a new approach to chronic disease. Personalizing chronic disease management can be improved by using biosensors and advanced communication technology. Recent advances in miniature wireless sensors supported by ubiquitous computing have fostered a growth of interest in wellness and illness management based on distributed sensor networks. A variety of factors need to be considered for effective integrated scheduling scheme that can assign sensing, computation, and communication task to different sensor nodes to assist them set priority of the task at hand. In this paper, we present a framework for integrated scheduling algorithm for sensing, computation, and communication tasks within a distributed intelligent sensor network. Preliminary simulation results are presented for linear daisy chain network with different number of sensor nodes that consider various sensing and communication speeds.

I. INTRODUCTION

The rapid escalation of American health care costs compels a new approach to chronic disease. Personalizing chronic disease management can be improved by using biosensors and advanced communication technology [1-2]. Recent advances in miniature wireless sensors supported by ubiquitous computing have fostered a growth of interest in wellness and illness management based on distributed sensor networks. The miniature and unobtrusive sensor nodes can be enclosed in patches or clothing (wearable sensors), or embedded in furniture and building structures (environmental sensors). Such a distributed sensor network will allow individuals to monitor, over extensive period of time (after they leave operation room and intensive care unit), their physiologic parameters frequently during the day. Pioneer research projects have set up small scale sensor network systems[3] to help physicians keep track of their patients whose chronic condition includes risk of sudden acute events where early intervention may significantly improve the survival rate and reduce the recovering time. However, these systems all require manual intervention from the physician / nurse and/or individuals, and cannot accommodate the power restriction and ad hoc intelligent sensor network. One of the fundamental services that are necessary to achieve the automatic data acquisition and feedback for chronic disease management is an integrated scheduling scheme that can assign sensing, computation, and communication task to different sensor node to assist them set priority of the task at hand.

In this paper, we present a framework for integrated scheduling for sensing, computation, and communication tasks within a distributed intelligent sensor network [3-4]. We then formulate the integrated scheduling algorithm for intelligent sensor network as an optimization problem. The objective is to minimize the total time used to accomplish certain sensing task (including necessary computation and communication), while considering the mobility, and the power consumption and storage each sensor node. We consider a linear daisy chain network of sensors to investigate the effect of communication link speed and sensing or measuring speeds on the total response time of the system. Our preliminary simulation results show that it is important to evaluate the combined effectiveness of scheduling protocols and data size.

The rest of the paper is as follows. Sections II discusses related work in divisible scheduling and wireless sensor networks. In section III, we present our proposed model and discuss details of the scheduling strategies and protocols. Section IV presents our simulation results with detailed discussion on the effect of various parameters on the total response time. Finally, in section V we conclude and point to future work.

II. RELATED WORK

In recent times the interest in wireless network based sensor generated data processing has grown considerably. With the advances of wireless and mobile communication technology, sensor network, wearable medical devices, emerging applications that will potentially improve general living standard in underserved populations need to be developed and implemented. An important problem in the application of wireless sensor networks is to decide how to achieve a balance in the job distribution between sensor nodes so that data sensing and hence response time is minimal. Inspired by this promising challenge, we propose to apply divisible load scheduling theory (DLST) [5-7] that permits the partitioning of large processing job into smaller fractions to be processed independently so that the partial solutions can be consolidated to construct the complete solution to the problem.

Manuscript received April 3, 2006. This work was supported in part by the New Faculty Research Grant of the University of Houston and the Abramson Family Center for Future of Health. Dr. Yuan (phone: 713-743-1129; fax: 713-743-4032; e-mail: xyuan@uh.edu) and Dr. Moges (mmoges@uh.edu), are with the University of Houston, the College of Technology, Houston, TX 77204, USA.

The initial application of DLST was motivated by the objective of integrating communication and computation in distributed sensor network modeling. Most of these studies develop an efficient allocation of load to processors over a network by forcing the processors to all stop processing at the same time. Intuitively, this is because the solution could be improved if some processors were idle while others are still busy [4]. However, with increasing complexity of the sensor network applications, the sensor nodes are not only required to gather and blindly relay information upward, but also expected to have some "intelligence" enabling the interaction of sensors and/or systems to yield improved safety and effective operation of a specific application.

To do so, in this paper we introduce a new parameter: data sensing capacity to the existing only communication and computation model. We assume sensor nodes make data sensing, perform computations on the sensed data and communicate to the other nodes to gain the benefits of parallel processing. The first target network topology to be examined in this paper is that of linear daisy chain. In this case control processor partitions the total job and communicates the load fractions to the nearest available sensor node S_1. The sensor node S_1 starts its assigned sensing job and simultaneously communicates the rest load fractions to the next nearest sensor node S_2. Similarly, the sensor S_2 starts sensing immediately upon receiving its assigned load fraction. This process of communication and sensing of the respective sensor nodes continues until all available sensors receive their respective assignments.

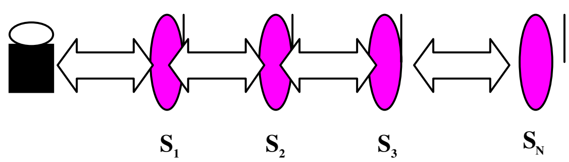


Fig 1. Linear Daisy Chain Network of N Sensor

III. SYSTEM MODEL

In this section, the various network parameters used in this paper are presented along with some notation and definitions. The network topology discussed in this study is the linear daisy chain network consisting of one destination/control processor and N communicating sensor nodes as shown in Fig. 1. It will be assumed that the total load considered here is of the arbitrarily divisible kind that can be partitioned into fractions of loads to be assigned to each processor over a network. In this case the destination processor first assigns a load share to be sensed to each of the N sensor nodes and then receives the sensed data from each sensor node. Each sensor node begins to sense its share of the load once the sensing instructions from the controller have been completely received by each sensor node. We assume that computation time is negligible compared to communication and sensing time. This is a reasonable assumption in some situations for the reasons given above.

A. Notation and Definitions:

α_i: The fraction of load that is assigned to i^{th} sensor-node by the control processor.

y_i: A constant that is inversely proportional to the sensing speed of i^{th} sensor-node in the network.

z_i: A constant that is inversely proportional to the communication speed of i^{th} link in the network.

T_{ms}: Sensing intensity constant. This is the time it takes the i^{th} sensor node to accomplish the whole sensing task when $y_i = 1$. The entire assigned sensing task can be sensed on the i^{th} sensor node in time $y_i T_{ms}$.

T_{cm}: Communication intensity constant. This is the time it takes to transmit the entire load over a link when $z_i = 1$. The entire load can be transmitted over the i^{th} link in time $z_i T_{cm}$.

T_i: The total time that elapses between the beginning of the scheduling process at t=0 and the time when sensor node i completes its responding, i = 1, . . . , N.

T_f: This is the time when the last processor finishes responding (finish time or make-span).

$$T_f = \max(T_1, T_2, \ldots, T_N).$$

B. Simultaneous Sensing Start, Sequential Responding (S^4R) Strategy

There may be different strategies by which the controller communicates with the sensor nodes and the nodes sense and report their data. In this study we consider the case where the destination/controller processor partitions the total load to the available sensor nodes in the system and communicates the load fractions to the nearest available sensor node S_1. The sensor node S_1 starts sensing the load fraction α_1 and simultaneously communicates the rest load fractions to the next nearest sensor node S_2. Similarly, the sensor S_2 starts sensing immediately upon receiving the load fraction α_2. This process of communication and sensing of the respective sensor nodes is shown by means of a Gantt-chart-like timing diagram in Fig. 2. In this timing diagram the communication time is shown below the time axis and the sensing time is shown above the time axis for all sensor nodes in the network.

The timing diagram shown in Fig. 2 shows that at time t = 0, the sensor nodes are all idle and the control processor starts to communicate (shown above the time axis) with the nearest sensor node in the network. This process of communication continues among the neighboring sensor nodes and by time $t = t_1$, each sensor node will receive its sensing instructions from the control processor. This may correspond to a situation where sensing shall commence sequentially beginning from the nearest and ending at the furthest located sensor node. After sensing jobs are made (shown below the time axis), we assume that only one sensor node may report back to its neighbor node at a time. In this situation only sensor node S_1 will be able to communicate with the control node to report all the sensed data from all the sensor nodes.

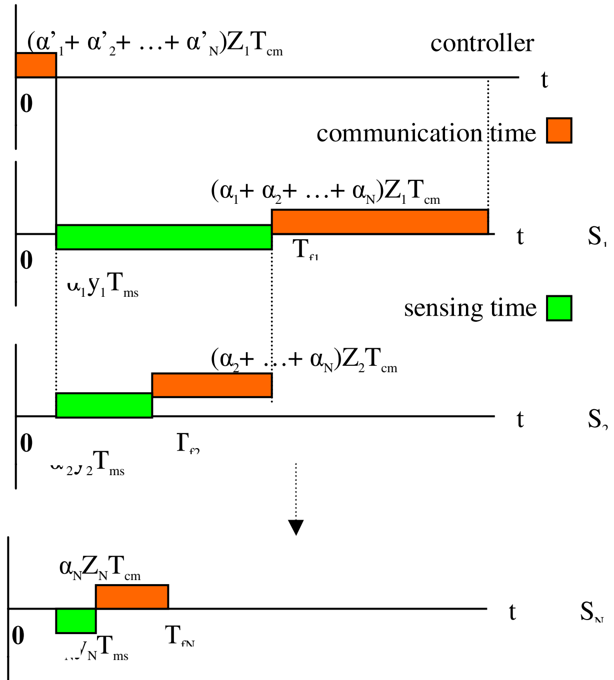


Fig 2. Timing diagram of a Simultaneous Sensing Start Sequential Responding (S^4R) load scheduling strategy in a linear daisy chain network of N sensor nodes with a controller

The equations that govern the relations among various variables and parameters in the network shown in Fig. 2 can be written as follows:

$$T_1 = \alpha_1 y_1 T_{ms} + (\alpha_1 + \alpha_2 + \dots + \alpha_N) z_1 T_{cm}$$

$$T_2 = \alpha_2 y_2 T_{ms} + (\alpha_2 + \alpha_3 + \dots + \alpha_N) z_2 T_{cm}$$

… …

$$T_N = \alpha_N y_N T_{ms} + \alpha_N z_N T_{cm}.$$

Using the assumption that the total task assignment originating at the control node is normalized to a unit load, the fractions of the total sensing load should sum to one:

$$\alpha_1 + \alpha_2 + \dots + \alpha_N = 1.$$

Based on the above equations and the timing diagram shown in Fig. 2, one can write the following set of recursive equations:

$$\alpha_1 y_1 T_{ms} = \alpha_2 y_2 T_{ms} + (\alpha_2 + \alpha_3 + \dots + \alpha_N) z_2 T_{cm}$$

$$\alpha_2 y_2 T_{ms} = \alpha_3 y_3 T_{ms} + (\alpha_3 + \alpha_4 + \dots + \alpha_N) z_3 T_{cm}$$

… …

$$\alpha_i y_i T_{ms} = \alpha_{i+1} y_{i+1} T_{ms} + (\alpha_{i+1} + \dots + \alpha_N) z_{i+1} T_{cm}$$

… …

$$\alpha_{N-1} y_{N-1} T_{ms} = \alpha_N y_N T_{ms} + \alpha_N z_N T_{cm}.$$

The equations given above are used to find the optimal allocations of sensing task that minimize the total response time, T_f, in the context of this particular scheduling policy and interconnection topology. It is interesting to note that if time is reversed, the timing diagram of Fig. 2 for sensing and responding time is equivalent to standard divisible load models of computation and communication for sequential distribution in linear daisy chain network without front-end processors [5]. In this case the processors receive their share of load from the root processor sequentially from the neighboring processors and start computation after completely receiving their share of load.

Now using the above sets of equations and the normalization equation, we solved α_i for a homogeneous sensor network with up to nine sensor nodes. That is, the communication speed $z_i = z$, and the sensing speed $y_i = y$, and communication intensity and sensing intensity is set to one, i.e., $T_{ms} = T_{cm} = 1$. The control processor will use the α_i to decide the sensing coverage of each sensor node. The minimum sensing and responding time of the network will then be given as:

$$T_f = \alpha_1 y_1 T_{ms} + (\alpha_1 + \alpha_1 + \dots + \alpha_N) z_1 T_{cm}$$

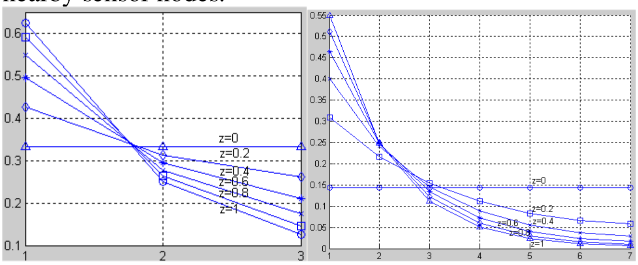
IV. PRELIMINARY SIMULATION RESULTS

Equation 1 and 2 show the solutions for work load α_i with 3 and 3 sensor nodes.

$$[\alpha_1, \alpha_2, \alpha_3]^T = \begin{bmatrix} \frac{y^2 + 3yz + z^2}{3y^2 + 4yz + z^2} \\ \frac{y}{3y + z} \\ \frac{y^2}{3y^2 + 4yz + z^2} \end{bmatrix} \qquad (1)$$

$$[\alpha_1, \alpha_2, \alpha_3, \alpha_4]^T = \begin{bmatrix} \frac{y^3 + 6y^2z + 5yz^2 + z^3}{4y^3 + 10y^2z + 6yz^2 + z^3} \\ \frac{y(3yz + y^2 + z^2)}{4y^3 + 10y^2z + 6yz^2 + z^3} \\ \frac{y^2(y+z)}{4y^3 + 10y^2z + 6yz^2 + z^3} \\ \frac{y^3}{4y^3 + 10y^2z + 6yz^2 + z^3} \end{bmatrix} \qquad (2)$$

Graphical representative solutions for α_i for a sensor network with three, five, seven and nine sensor nodes are shown in Figure 5. The IPU will use the α_i to decide the sensing coverage of each sensor node. Figure 5 shows the task assignment α_i versus number of sensor nodes (3, 5, 7, and 9 sensor nodes) with variable inverse communication speed z and fixed sensing speed y (y=1.0). When the communication is ideal, i.e., z = 0, every sensor nodes get same proportion of the task, and contribute to the improved performance of the senor network. With the decrease of the communication speed, the first sensor node will be assigned bigger portion of the task (reaches 55% when z = 1), and the sensor nodes located farther away assigned much smaller portion of the task (goes towards 0 when z = 1 for the 7th and 9th node). When the communication speed decreases, the communication time will dominate the response time of a task. Thus, in order to achieve better response time, it is intuitive for the IPU assign bigger fraction of a task to nearby sensor nodes.



(a) Three Sensor Nodes (b) Seven Sensor Nodes

Figure 3 Assigned task (α_i) for three and seven sensor nodes

The total finish time is plotted against number of sensor nodes when the inverse communication speed (z_i) is varied and the inverse sensing speed (y_i) is fixed (Figure 5). This scenario simulates the effect of the distance between IPU and ISNs and its effect on the behavior of the total finish time. In general, the sensing speed determines the boundary for the total finish time. When the communication slows down, either due to the decreased bandwidth available, or the increasing of distance, the effect of increasing the number of sensor nodes to reduce the total finish time is reduced. That is, the number of effective sensors decreases[1]. When communication speed reduces to certain value, the number of effective sensors is reduced to three for the linear daily chain network protocol. Adding more sensor nodes will not improve the performance.

V. Conclusion

We have investigated the problem of assigning of data in a linearly daisy chained network of sensors, with the objective of optimizing response time as well as sensor lifetime. We formulated an integrated intelligent sensor network scheduling problem in terms of minimizing the total processing time of a divisible sensing task while keeping the energy consumption low. Various aspects of the algorithm such as computational complexity, impact of network structure and starting node, and dynamic and static scheduling, are discussed. Experimental results for a linearly chained sensor network with up to ten nodes show that the S^4R scheduling strategy can minimize the total processing time while considering the power storage and mobility of each sensor node. The results showed that the number of effective sensor node approaches three when using linear daisy chain network protocol, which confirms the disadvantage of a linear daisy chain network protocol – the protocol limited the number of effective nodes that can be connected.

A wide spread of network topologies and job distribution protocols and strategies can be instantiated from this study. We plan to investigate more realistic scenarios and network structures based on experimental verifications to supplement our proposed model analysis in the future.

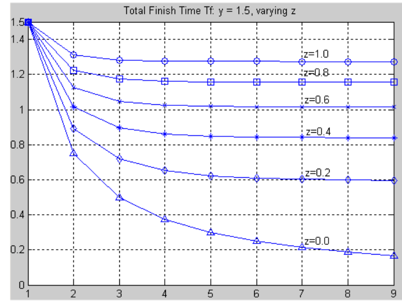


Figure 4 Finish Time T_f versus number of sensor nodes for linear daisy chain homogeneous network with variable inverse communication speed z, when the inverse sensing speed is fixed, y = 1.5.

References

[1] Kaushal R, Blumenthal D, Poon EG, Jha AK, Franz C, Middleton B, Glaser J, Kuperman G, Christino M, Fernandopulle R, Newhouse JP, Bates DW, and and the Cost of National Health Information Network Working G, The Costs of a National Health Information Network. Ann Intern Med, 2005. 143(3): p. 165-173.

[2] Emil Jovanov, Aleksandar Milenkovic, Chris Otto, and Piet C De Groen, A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation. Journal of NeruoEngineering and Rehabilitation, 2:6, March 2005.

[3] Yuan, X., Li, X., Buckles, B., 2004. Real-time sensor validation and fusion for distributed autonomous sensors. Proceeding of SPIE2004.

[4] Y. Chen, X. Yuan, Collaborative Decision Making for Hazardous Substance Monitoring, NSS, June, 2005, San Diego, Californiz USA.

[5] Park S, Jayaraman S: Enhancing the Quality of Life Through Wearable Technology. IEEE Engineering in Medicine and Biology Magazine 2003, 22(3): 41-48.

[6] V. Bharadwaj, D. Ghose, V. Mani, and T.G. Robertazzi, "Scheduling Divisible Loads in Parallel Distributed Systems," IEEE Computer Society Press, Los Alamitos, CA, 1996.

[7] V. Bharadwaj, D. Ghose, T.G. Robertazzi, "Divisible Load Theory: A new paradigm for load scheduling in distributed systems," Cluster Computing, Vol. 6, pp. 7-18, 2003.

[8] T.G. Robertazzi, "Ten reasons to use divisible load theory, Computer," Vol. 36, pp. 63-68, 2003.

[9] J. Sohn and T.G. Robertazzi, Optimal divisible load sharing for bus networks, IEEE Transactions on Aerospace and Electronic Systems, Vol. 32, pp. 34-40, 1996.

[10] Y.C. Cheng and T.G. Robertazzi, Distributed computation with communication delays, IEEE Transactions on Aerospace and Electronic Systems, Vol. 22, pp. 60-79, 1988.

[1] The sensor nodes that can help reduce the total finish time is considered as effective sensor nodes.